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Natural Hazards
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Discussions

Interactive comment on "Defining scale thresholds for geomagnetic storms through statistics" *by* Judith Palacios et al.

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This manuscript analyses the statistical distribution of geomagnetic variability using a 15-year long high-quality and high-cadence dataset developed by the authors. They use this dataset to determine thresholds above which the Spanish Space Weather service should issue warnings that geomagnetic variability has reached high levels that may warrant actions by operators of systems (such as power grids) that are at risk from high geomagnetic variability.

This is an elegant approach, not least through the authors' use of a local geomagnetic index customised to their target service area in Spain, also through their study of a wide range of statistical functions to find a function that most suits the geomagnetic variability observed in Spain. However, I consider that their approach, while mathematically consistent, is poorly suited to the practical task of managing the space weather risk to vulnerable systems:

a. most importantly there is no consideration of the system response to geomagnetic variability. This response is central to the setting of space weather thresholds. For example, a power grid operator will be concerned with the size and durations of geomagnetic induced currents passing through their transformers and how these are likely to degrade or even damage the transformers. This requires consideration of (a) how sub-surface geology (ground impedance) converts geomagnetic variability into geoelectric fields, and (b) how power grid topology determines the GIC flows driven by those geoelectric fields, especially if this leads to hot spots with high GIC (e.g. due to edge effects in the grid, and coastal enhancements of geoelectric fields). There are a number of published papers that have examined these issues in respect of the Spanish power grid, so I strongly encourage the authors to assess how their results can be linked to those studies and, in particular, to consider whether their risk thresholds need to be adjusted to levels of geomagnetic variability that can produce GICs that might challenge transformer and grid operations in Spain. I suspect that this is likely to require a substantial increase in the risk thresholds, but a final result will depend on comparison of the present work with existing literature on GIC flows in the Spanish power grid.

b. as a secondary issue, I note that the authors' risk thresholds are well below the 1-in-100 and 1-in-200 year levels customarily used by government risk managers and by insurance industry. If one considers that the target risk from space weather is akin the Carrington event of 1859, one should consider the likelihood of severe geomagnetic event over any particular location, such as Spain, with that event lasting up to one hour (as in the Mumbai/Colaba observations from 1859, also the failure of the Hydro-Québec grid in 1989). The 1-in-100 year likelihood of a single one-hour duration event is around one in a million, well above the threshold probabilities used by the authors. Thus I recommend that they also consider adjusting their risk threshold to better match those widely used by emergency management authorities and the insurance industry – and to see how these thresholds compare with risk thresholds linked to system response as discussed under point a above.

For these reasons, I recommend that the authors make a major revision of the manuscript to bring it into better alignment with the wealth of published literature on space weather risks, especially to power grids including studies of space weather impacts on power grids in South Africa, Australia, Brasil, New Zealand, plus regions of the US and Europe. I include some examples below – but also see references in those papers. I would particularly highlight the South Africa and Australian studies as having magnetic latitudes, and perhaps geologies, that are comparable to Spain.

In addition I recommend that the authors address the minor comments and typographical issues listed below.

Minor comments

1. Page 1, line 24. This statement that geomagnetic disturbances decrease Earth's magnetic field is incomplete. This decrease is generally true where and when the disturbance is caused by the ring current, also by westward electrojets, but sudden impulses and eastward electrojets can produce increases that have very significant effects. Rotational disturbances of the field are also thought to have very important effects. Please update to reflect this.

2. Page 2, line 14. Suggest to cite the description of Dst, not as a plain URL, but rather as a reference to "Sugiura and Kamei, 1991" so as to recognise Sugiura's key role in developing Dst. Then reference as "Sugiura, M. and Kamei, T.: Equatorial Dst index 1957–1986, in IAGA Bull., 40, edited by A. Berthelier and M. Menvielle, ISGI Publ. Off., Saint-Maur-des-Fosses, France, 1991." I suggest to also note that this is available via the Kyoto URL than you have here.

3. Page 2, line 26. Please make clear than this raw K is calculated for a specific magnetic observatory, e.g. as shown at http://www.obsebre.es/en/currentvariationshortasj for daily K indices from the Ebro geomagnetic observatory.

4. Page 2, line 27. This is potentially confusing as written. The key point is that A is derived from a linearised version of K, specifically that 3-hourly K indices are converted to 3-hourly linear indices, denoted by lower case a - and only then averaged to derive a daily A index. Please clarify the text.

5. Page 2, line 29. The description of Ap is incomplete and perhaps confusing. The Ap index is the equivalent of Kp but follows a linear rather than a logarithmic scale. Both Kp and Ap exist in 3 hour and 24 hour versions. The 3 hour Ap is usually denoted in lower case, i.e. ap. Please clarify the text.

6. Page 2, line 35. I suggest to explicitly state that G1 to G5 is equivalent to Kp 5 to 9.

7. Page 3, line 6/7. Since you raise here the issue of high cadence, it would be appropriate here to introduce SYM-H as higher cadence development building on Dst. SYM-H is used later (page 9, line 2) without any introduction.

8. Page 3, lines 11/13. Please also cite work of other groups who have noted the importance of local disturbances, e.g, papers by Antti Pulkkinen and Chigo Ngwira (see list of reference below)

9. Page 10, lines 27 to 29. The discussion about dataset size may be mathematically correct, but does it have any significance for the physics or risk management? In risk management, e.g. assessment of flood risks, one typically requires a dataset that is at least 5 times longer than the longest return time that you wish to consider. This is a huge challenge for all space weather studies because our datasets are short, typically a few decades. Whilst the high cadence gives a lot of data, the dataset includes only a small number of significant space weather events, particularly the October 2003 events, and none of the larger historical events such as the Carrington event of 1859,

the Railroad Storm of 1921 or the March 1989 storm or some of the huge events in the 1940s and late 1950s. From a risk perspective, what matters is that the dataset includes a significant number of severe space weather events. In the present case, I think the discussion about dataset size is unhelpful and I recommend it be removed.

10. Page 11, line 15. I feel this neglects the importance of return period assessment. Return periods enable comparison with real world applications, so an important insight that can help designers of vulnerable systems such as power grids. For example, if there is a requirement for a transformer to have a design life of 50 years, it will help designers if we can estimate the probability of it being exposed to geomagnetic variability above some level during those 50 years. Please consider how to link your work to the assessment of return periods for severe events.

11. Page 11, line 16. Please explain briefly what are Q-Q plots, so that the reader does not need to search for an explanation.

Typographical issues

* Page 1, line 22, “do generate” may be better as “generates”

* Page 2, line 24, “originates” may be better as “leading to”

* Page 4, line 20, “compresses” may be better as “includes”

Some other power grid studies

Blake, S. P., P. T. Gallagher, J. McCauley, A. G. Jones, C. Hogg, J. Campanya, C. Beggan, A. W. P. Thomson, G. S. Kelly, and D. Bell (2016), Geomagnetically induced currents in the Irish power network during geomagnetic storms, Space Weather, 14, 1136–1154, doi:10.1002/2016SW001534.

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Divett, T., Ingham, M., Beggan, C.D., Richardson, G.S., Rodger, C.J., Thomson, A.W.P. and Dalzell, M., 2017. Modeling Geoelectric Fields and Geomagnetically Induced Currents Around New Zealand to Explore GIC in the South Island’s Electrical Transmission Network. Space Weather, 15(10), pp.1396-1412.

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Matandirotya, E., Cilliers, P.J. and Van Zyl, R.R., 2015. Modeling geomagnetically induced currents in the South African power transmission network using the finite element method. Space Weather, 13(3), pp.185-195.

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Torta, J.M., Marsal, S. and Quintana, M., 2014. Assessing the hazard from geomagnetically induced currents to the entire high-voltage power network in Spain. Earth, Planets and Space, 66(1), p.87.

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